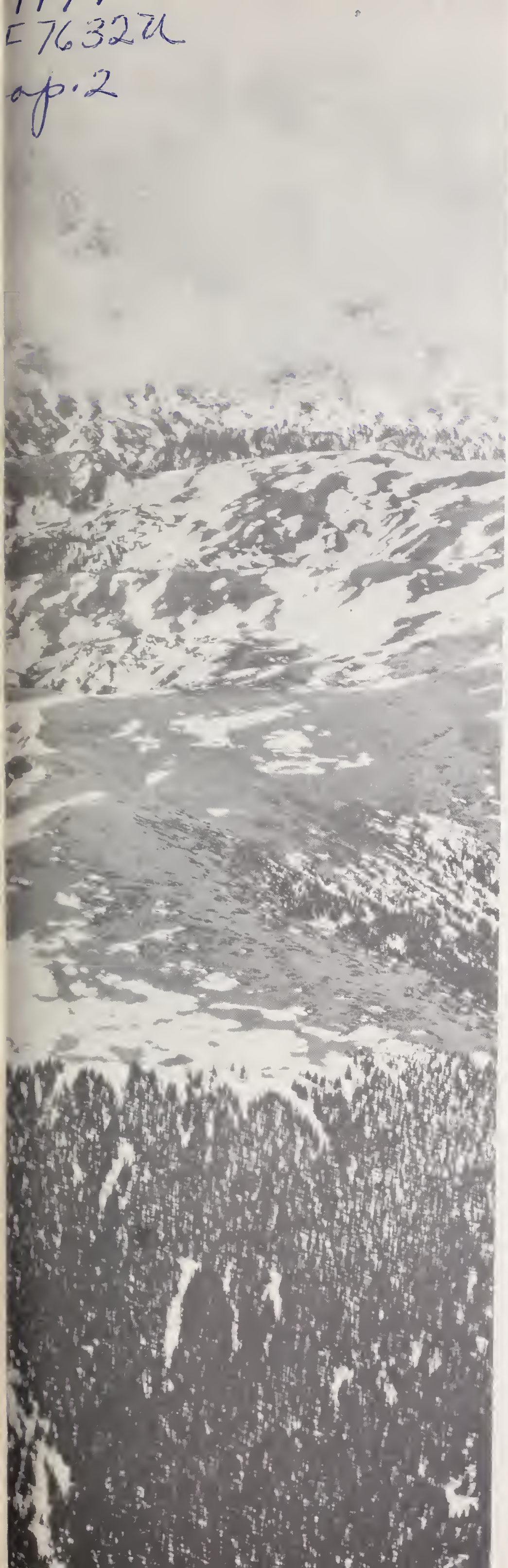

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The Weather and Climate of a High Mountain Pass in the Colorado Rockies

by

Arthur Judson

Rocky Mountain Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture

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Arthur Judson, Associate Meteorologist

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
221 Forestry Building Fort Collins, Colorado

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ERRATA

Page 8 - Tabulation, column 1. Dates for 48 hrs. and 72 hrs. snow fall amounts should be transposed.

Page 9 - Line 2, second paragraph, should read, "Average maximum depth ...

Page 16- Table 5. Headings under "Corresponding surface wind at Berthoud Pass" should read: Within ±22.5° Greater than ±22.5°

Page 20- Last paragraph, line 3. Delete the word, four.

Page 28- Figure 26. Regression equation should read: $\hat{Y} = 0.79 + 0.94X$

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Rocky Mountain Forest and Range Experiment Station [1]

[1]Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

CONTENTS

The Weather and Climate of a High Mountain Pass in the Colorado Rockies

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The need for avalanche control to protect lives and property is becoming more apparent in the Colorado Rockies where winter sports are skyrocketing and automobile travel is constantly increasing. Basic to avalanche research, however, are weather and climatic data representative of Colorado's avalanche zones at elevations between 10,000 and 12,000 feet mean sea level (m.s.l.).

The snow and weather data accumulated at Berthoud Pass (figs. 1,2) during the past 15 years, plus information collected irregularly for several preceding years, constitute one of the most complete sets of winter-environment records ever taken in the western alpine region. The data gathered by several individuals and agencies have been assembled and published here because of their importance to mountain meteorology and avalanche-control planning. Data are presented by two periods: I--Winter (November 1 - April 30), and II--Spring-Fall (May 1 - October 31); basic data are in the appendix (tables 7-15 and figures 23-26).

Berthoud Pass is in north-central Colorado, 45 miles west of Denver. The first all-weather mountain highway to traverse the Colorado Rockies, U.S. 40, crosses the Continental Divide at Berthoud Pass. The presence of numerous avalanches along and adjacent to the highway (Frutiger 1964)[2] and the winter resorts in this heavily traveled area, together with the accessibility of power, make the Berthoud Pass vicinity a desirable location for alpine snow and avalanche research.

The Pass is on an east-west section of the Continental Divide (latitude 39°48'N., longitude 105°47'W), at an elevation of 11,315 feet m.s.l. Peaks rise 1,000 to 2,000 feet above the Pass on both the east and west (fig. 2). Mature Engelmann spruce and subalpine fir are the dominant vegetation, with the upper limit of tree growth at 11,800 feet.

BACKGROUND INFORMATION

Mr. Clyde E. Learned,[3] Senior Highway Engineer, U. S. Bureau of Public Roads, began recording snowfall and snow depth at Berthoud Pass in 1926, and continued until 1939; however, several periods of record between 1926 and 1931 were not located. No data were taken from 1940-41. From 1942 to 1949, the U. S. Forest Service recorded snow depths. On October 1, 1949, W. M. Borland,[3] Hydrologist, U. S. Bureau of Reclamation, established the weather station at the Pass in cooperation with the 5002nd USAR Research and Development Unit (Tng.), Elmer E. Fryar Army Reserve Center, Federal Center, Denver, Colorado.

The U.S. Forest Service took over the station in 1950 as part of its avalanche-forecasting program, and in January 1951 assigned Richard M. Stillman[3] as the avalanche hazard forecaster. Fairly complete records are available for the 1950-61 winter period, November 1 through April 30. Year-round daily observations were initiated in June 1961. In September 1963, Berthoud Pass became an official U.S. Weather Bureau Climatological Station.

During the 1926-39 period, the master snow-depth stake was in a clearing a quarter of a mile north of the Pass; new-snow depths

[2] *Names and dates in parentheses refer to Literature Cited, p. 23.*

[3] *The author wishes to thank Messrs. Borland, Learned, and Stillman for the generous use of the original data which made this publication possible.*

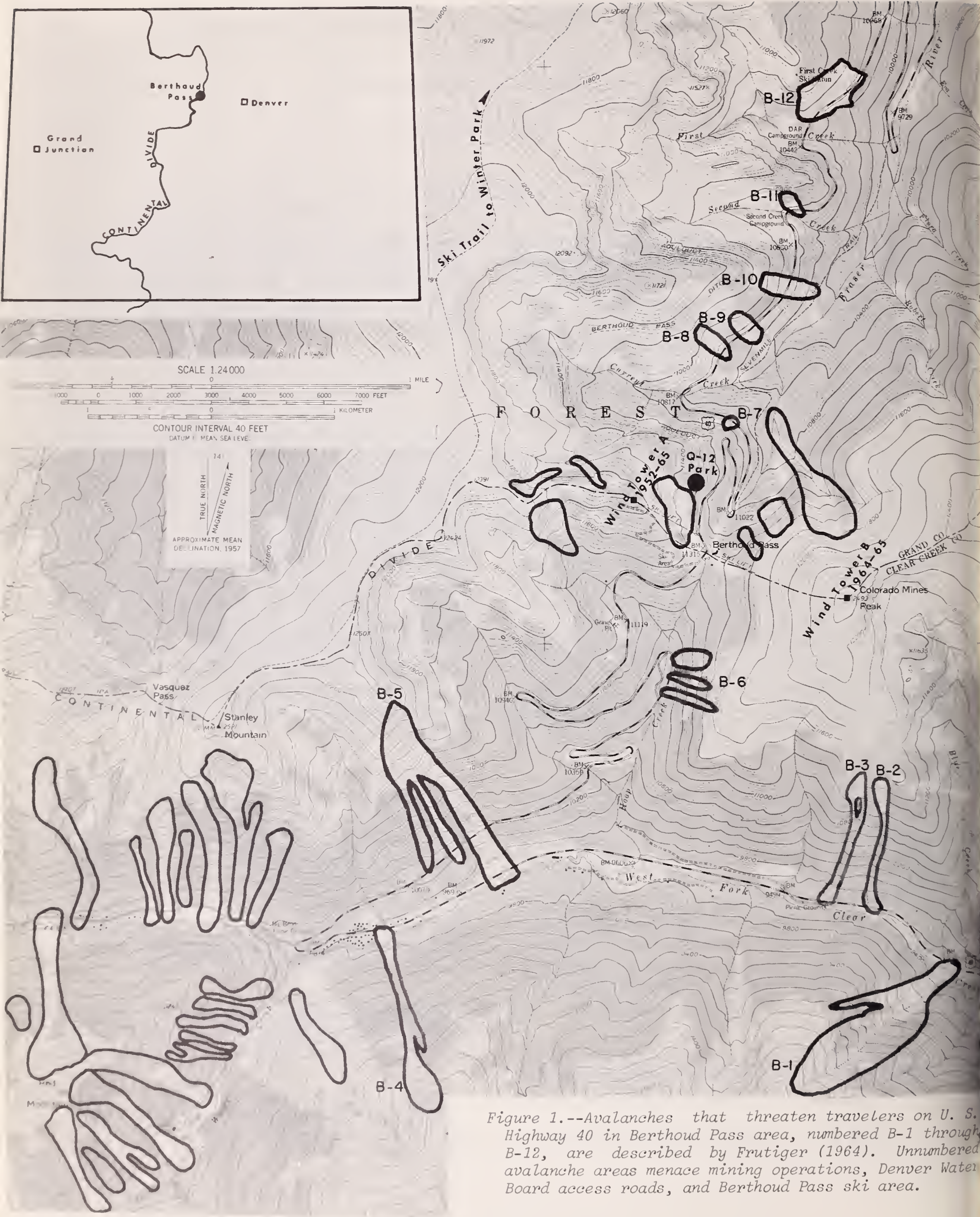


Figure 1.--Avalanches that threaten travelers on U. S. Highway 40 in Berthoud Pass area, numbered B-1 through B-12, are described by Frutiger (1964). Unnumbered avalanche areas menace mining operations, Denver Water Board access roads, and Berthoud Pass ski area.

Figure 2.--U. S. Highway 40 crosses Continental Divide at Berthoud Pass, 45 miles west of Denver, Colorado. The peaks on the east and west rise 1,000 to 2,000 feet above the Pass.

Colorado Mines Peak as seen from the upper terminal of chair lift above Berthoud Pass, January 4, 1964. Wind tower B was installed on the exposed summit at 12,493 feet m.s.l. in 1964.

Summit of Berthoud Pass as seen from Colorado Mines Peak, April 23, 1963. A, ski lodge and snow ranger's station; B, upper terminal of chair lift on ski area.

were measured at the present ski lodge site. When measuring was resumed in 1942, the master stake was 50 feet east of the lodge. In 1949, a precipitation tower was constructed and all instruments, including the snow depth stake, were relocated 100 feet northwest of the lodge. Maximum and minimum liquid-in-glass thermometers and a hygrothermograph were installed in a standard cotton region shelter. Mounted on top of the tower were a standard 8-inch rain and snow gage with its orifice 16 feet aboveground, a 3-cup anemometer with the cups 19 feet aboveground, and the instrument shelter with its base 11 feet 4 inches above the ground (Borland 1952).

In December 1951, a Leopold Stevens Q-12 recording precipitation gage[4] was installed in a clearing a quarter of a mile northwest of Berthoud Pass--since called Q-12 Park (fig. 3). In November 1959, however, the Q-12 gage was replaced with a Bendix Friez 775-B recording rain and snow gage, the orifice of which was placed 13 feet 4 inches aboveground. The master snow-depth stake and 8-inch gage were moved to Q-12 Park in December 1952. New-snow depths have been measured at the Q-12 location on a white snowboard since that date.

The instrument shelter, moved to Q-12 Park on August 29, 1963, was mounted inside a metal frame (fig. 3) so the bottom of the shelter can be kept approximately 4 feet above the snow surface throughout the winter.

A new precipitation tower was constructed in Q-12 Park in October 1964. The orifices of the recording gages on this tower are 14 feet 10 inches aboveground. Also installed at Q-12 Park that year was an experimental 12-foot-diameter pressure pillow (fig. 3) which, with a type F water-level recorder, will record the water equivalent of the snowpack on the ground. The pillow, developed by the U. S. Soil Conservation Service, has been successfully used in other western States.[5]

[4] *Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

[5] *Personal communication with Robert Beaumont, U. S. Soil Conservation Service, Portland, Oregon, 1964.*

Bimonthly stratigraphic section data have been taken regularly at Q-12 Park for the past 15 winters. Pits were dug to expose the layers of snow on the ground. Data for each layer include: (1) temperature, (2) density, (3) settlement, (4) hardness, (5) resistance to penetration, (6) crystal type, and (7) grain size. These data will be analyzed and published later.

The anemometer, located northwest of the ski lodge in 1949, was moved on January 27, 1952, to a point 325 feet west of the upper chair-lift terminal at an elevation of 11,900 m.s.l., where it was mounted 12 feet aboveground on a steel tower. An Esterline Angus operations recorder, installed at the snow ranger's headquarters, continuously records windspeed and direction. In November 1961, the anemometer tower was moved to 10 feet north of the upper chair-lift terminal, and was mounted on the northwest corner of the lift operator's shack. The beaded, conical 3-cup anemometer was then 24 feet aboveground. The anemometer was moved again on August 29, 1963, to a site 100 feet west of the lift operator's shack, at 11,880 feet m.s.l., where it was mounted on a 33-foot tower (wind tower A, fig. 1; fig. 4).

In October 1964, a new wind station (wind tower B, fig. 1) was established on the exposed summit of Colorado Mines Peak at 12,493 feet m.s.l. Mounted on the tower, 39 feet aboveground, are windspeed and direction sensors, which are continuously recorded at the snow ranger's station at Berthoud Pass.

A partial list of the instruments operated during the avalanche season (November 1 through April 30), and the number of winters when data were recorded are:

	Number of winters
Barograph	13
Microbarograph	2
Standard mercurial barometer	3
Esterline Angus operations recorder (windspeed and direction)	14
Heated tipping bucket rain gage	3
Generating anemometers	3
Hygrothermographs	15
Temperature probes:	
In the snowpack	15
In the soil	2
On the anemometer tower	2

Pressure pillow to record water equivalent of snowpack on the ground. October 2, 1964.

Figure 3.--Q-12 Park, located one-fourth mile northwest of Berthoud Pass, has an average radius of 60 feet, an east exposure, and an average slope of 6 percent. The 60- by 120-foot area, well protected from wind, was artificially leveled in the fall of 1955. Mature Engelmann spruce and subalpine fir, 20 to 60 feet high, surround the opening.

Precipitation recording gage, shelter, and snow stakes. January 4, 1964.

Looking east over Q-12 Park to Mount Parry and Mount Eva on the Continental Divide, January 14, 1964.

Instrument shelter and snow-depth stake. Colorado Mines Peak in background. May 13, 1964.

NW
Jan. 4

W
Jan. 3

NNE
Jan. 4

Figure 4.--Four views from Berthoud Pass anemometer, 1964.

SW
May 13

PERIOD I: WINTER (NOVEMBER 1 - APRIL 30)

Thermal Regime

The small temperature variations typical of ridge-crest stations are common at Berthoud Pass (fig. 5; table 1), where the average daily range is only 15° F. in January. Maximums rarely exceed 32° F., and below-zero minimums are frequent during December, January, and February. Minimums below -25° F. are rare because terrain features and exposure are not favorable for the development of temperature inversions. The lowest temperature on record is -35° F. on February 1, 1951; the highest winter maximum, 56° F. on April 26, 1963.

Table 1. --Thermal regime at Berthoud Pass, Colorado, during winter period, November 1 - April 30, 1949-64

Period I	Mean	Maximum temperature			Minimum temperature			Average days--	
		Mean	Median	Extreme	Mean	Median	Extreme	Below 0° F.	Above 32° F.
	- - - - - -	- - - - - -	- - - - - -	Degrees F.	- - - - - -	- - - - - -	- - - - - -	Number	
November	20	29	31	47	11	12	-25	5	13
December	12	20	20	41	5	6	-23	9	3
January	11	18	19	40	3	4	-28	10	2
February	12	20	20	42	4	4	-35	9	3
March	16	25	26	49	6	6	-20	7	6
April	25	35	35	56	15	15	- 4	0.5	17

Snowfall

The snowfall season normally begins in September and ends in June. Mean annual snowfall for 1950-64 was 361 inches, with 289 inches falling from November through April:

	1931-39		1949-64
	Sept.-June (Inches)	Nov.-Apr. (Inches)	Nov.-Apr. (Inches)
Seasonal snowfall:			
Mean	413	347	289
Maximum	507	414	414
Minimum	318	278	169
Median	418	354	266

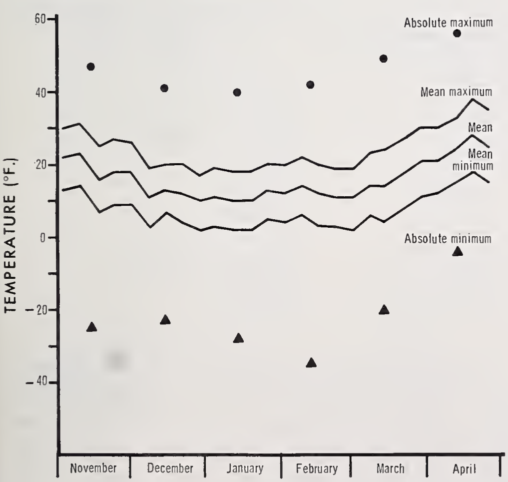
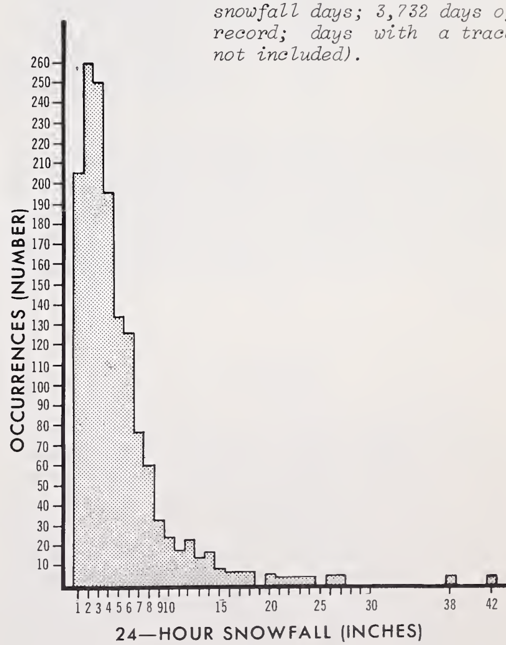


Figure 5.--Winter march of temperature (°F.)--7-day means and extremes. November through April 1949-64.

Snowfalls are frequent and light. They occur on 50 percent of the days (including traces), and exceed 12 inches only 3 percent of the time, although 24-hour snowfalls up to 42 inches have been recorded (fig. 6). The maxi-

Figure 6.--Distribution of 24-hour snowfalls at Berthoud Pass, November 1 - April 30, 1931-39 and 1949-64 (1,420 snowfall days; 3,732 days of record; days with a trace not included).



mum seasonal snowfall was 507 inches in the winter of 1932-33 (Learned 1939). The greatest snowfall in a calendar year was 518 inches in 1957.

Berthoud Pass receives about 20 percent more snowfall than other stations in the Front and Tenmile ranges (Borland 1963). Other stations are located at Loveland Basin, Arapaho Basin, Breckenridge (Peak 8), and the high-altitude observatory at Climax. The difference is related to the greater orographic effect at Berthoud Pass.

Snowfall intensities average 0.5 inch per hour during most storms, and sustained intensities exceeding 1 inch per hour are unusual even during major storms. Very high snowfall rates do occur about once every 4 years, however. The highest snowfall rates recorded at Berthoud Pass are:

	New snow		Date
	Rate (In./hr.)	Amount (In.)	
Time period:			
1 hr.	7.00	7	Feb. 25, 1934
2 hrs.	6.50	13	Feb. 25, 1934
13 hrs.	2.77	36	Apr. 21, 1933
24 hrs.	1.75	42	Apr. 21, 1933
48 hrs.	1.67	80	Apr. 20-22, 1933
72 hrs.	1.31	94	Apr. 20-21, 1933

Snowfalls of this magnitude have also been recorded at nearby Silver Lake, 19 miles north-northeast of Berthoud Pass, where 76 inches of snow fell in a 24-hour period on April 26, 1922--the largest 24-hour snowfall recorded to date in the United States (Ludlum 1962).

New Snow

Densities of 24-hour snowfalls during the winter months (fig. 7) show a mean value of 0.07 gram per cubic centimeter (g/cm^3), or a snow-water depth ratio of 14 to 1. The median and mode are also 0.07 g/cm^3. Only 8 percent of the total snowfalls had density values greater than 0.10 g/cm^3. Densities were computed from the ratio of the water equivalent to the new snow depth, measured by core samples taken from a white snowboard.

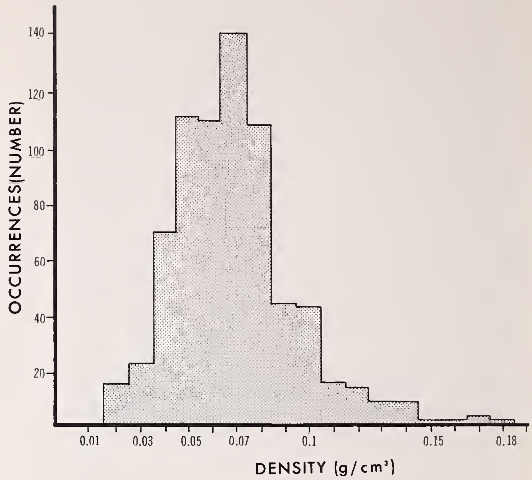


Figure 7.--Distribution of 24-hour snowfall density, Berthoud Pass, Colorado, 1949-64.

New-snow crystal types, classified according to the International Classification for Snow (Canada Natl. Res. Council 1954) and recorded for most snowfall days 1957-63, were distributed as follows:

Classification symbol:	Crystal form	Percent occurrence
F-7	Irregular	29
F-2	Stellar	24
F-5	Spatial dendrites	21
F-1	Plates	12
F-8	Graupel	9
F-4	Needles	2
F-9	Ice pellets	2
F-6	Capped columns	1
F-3	Columns	0
F-10	Hail	0

Surface hoar commonly forms during periods of clear, cold weather, but depths exceeding 1 inch are unusual. In the Berthoud Pass vicinity, rime ice accumulations below 12,000 feet m.s.l. are insignificant. Only once during the 15 winters of record has sufficient rime developed to inhibit the functioning of exposed instruments (fig. 8).

Figure 8.--Some rime ice has been encountered at wind tower B on the exposed summit of Colorado Mines Peak.

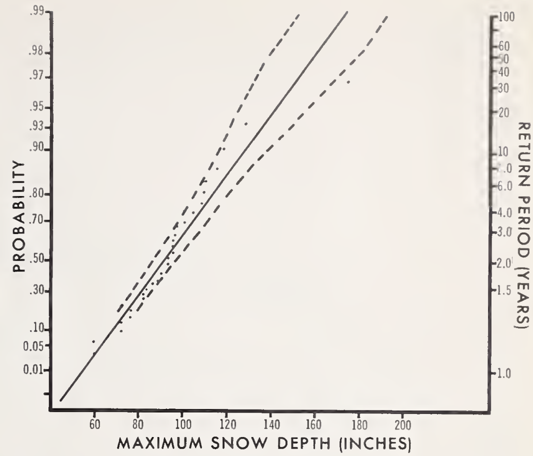


Figure 10.--Return periods for maximum snow depths; 30 years of record. (Shows least squares line of best fit and one standard error envelope.)

Snowpack

The seasonal snowpack begins in late October and reaches its maximum depth in mid-April (fig. 9). A continuous snow cover usually remains until the third week in June, although it may last until early July in years when May snowfalls are heavy and June temperatures are below average.

Recorded peak snow depths range from 60 to 174 inches. Average depth for the 1942-64 period was 88 inches. Return periods for maximum snow depths for 30 years of record (fig. 10) were determined by Gumbel's (1958) procedure.

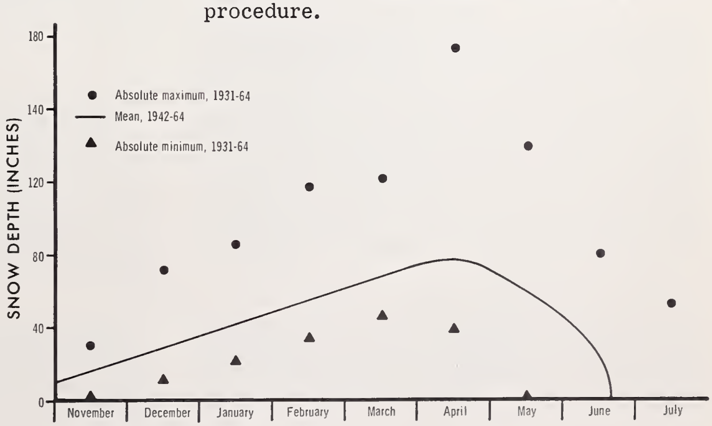


Figure 9.--Snow depths at Berthoud Pass (see appendix, tables 11 and 12).

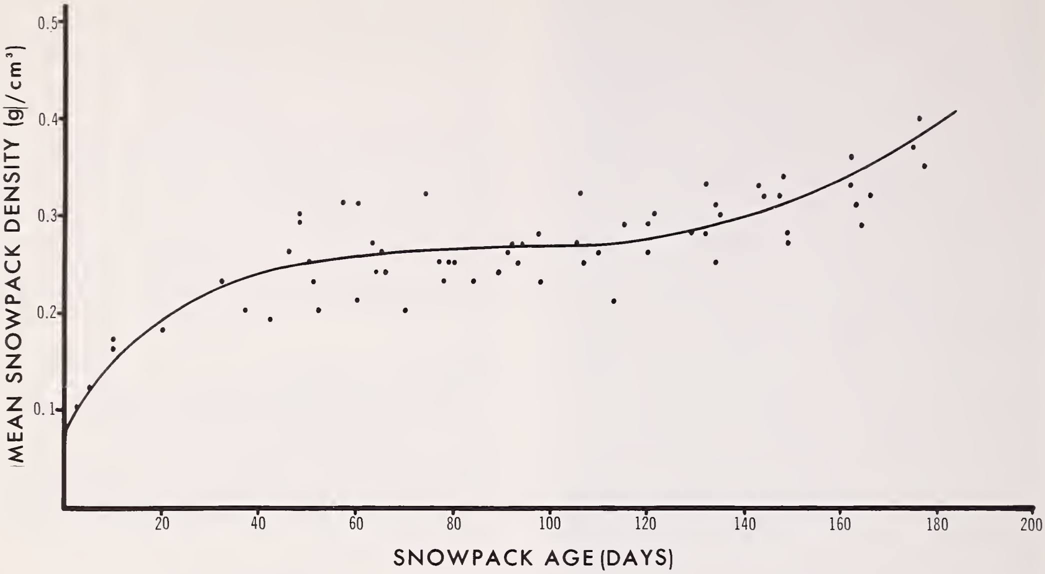


Figure 11.--Snowpack densification at Berthoud Pass, 1953-60.

Destructive metamorphism proceeds very slowly in the pack at Berthoud Pass. The combination of low temperature, porous snow, and shallow snow depth delays densification and causes the formation of large quantities of depth hoar near the ground. The low strength properties of these large, unstable crystals is a primary cause of avalanching in the alpine regions of this continental climate.

A rapid rise in density (fig. 11) during the first 20 days is followed by a marked decrease in rate of densification. More than 140 days are required before the mean snowpack density[6] reaches a value of 0.30 g/cm^3. After 140 days, the rate of densification gradually increases due to accelerated destructive metamorphism accompanying higher temperatures. The persistence of a low-density snowpack throughout the winter is largely responsible for the abundance of "rotten snow" found in the Rockies in May and June--whenever air temperatures are above freezing, over-snow travel is difficult and tiring. The layer of coarse-grained crystals and associated depth hoar becomes progressively more fragile as the pack becomes isothermal. This phenomenon, discussed by La Chapelle (The Mountaineers, Seattle 1960, chapter 21), is particularly evident on timbered north slopes.

[6]*For engineering purposes, the weight of the snowpack in pounds per square foot may be calculated by multiplying the water equivalent by 5.2; average density of 0.3 g/cm^3 is assumed.*

Wind

Windspeed and direction have been recorded at Berthoud Pass since January 1952. Six-hour averages of speed and direction, starting at 0000 hours each day, are available for the period of record (figs. 12, 13), with original strip charts available since November 1962.

The anemometer is located near the upper terminal of the chair lift on a ridgetop half a mile west of the Pass at 11,880 feet m.s.l. (see fig. 4). In addition, windspeed was con-

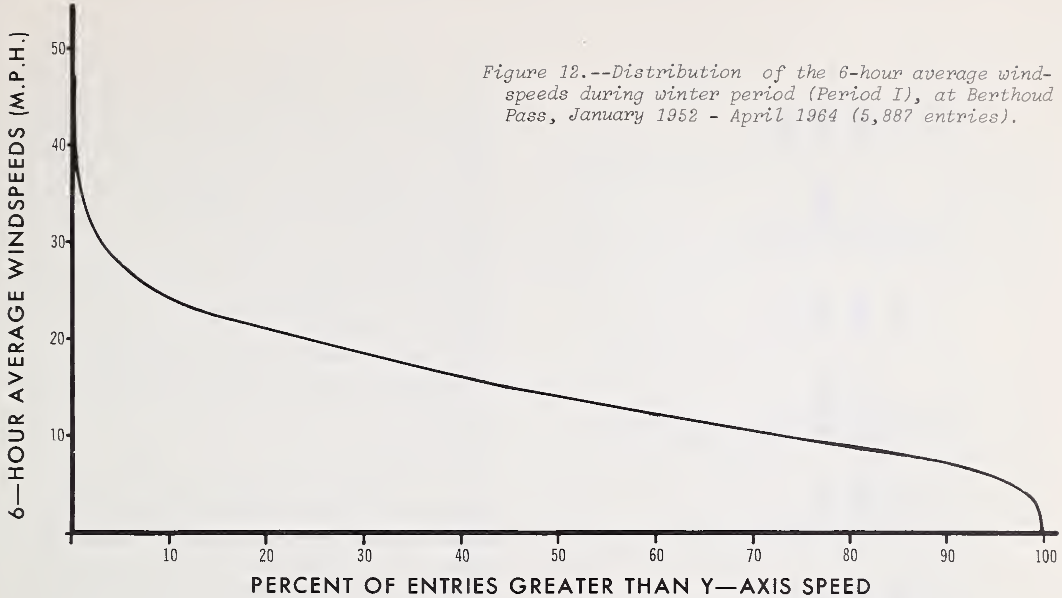


Figure 12.--Distribution of the 6-hour average windspeeds during winter period (Period I), at Berthoud Pass, January 1952 - April 1964 (5,887 entries).

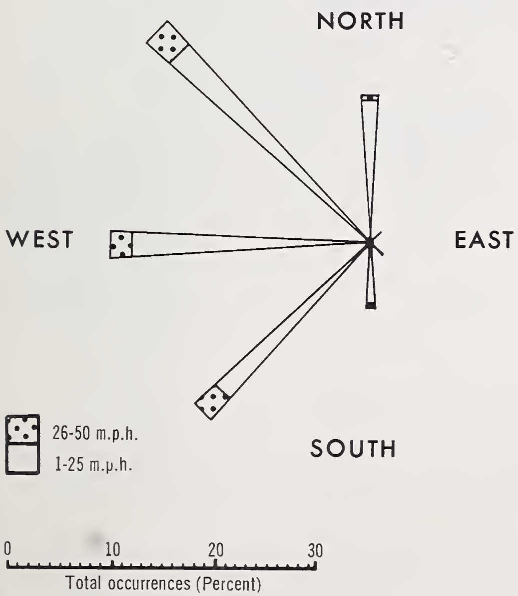


Figure 13.--Distribution of 6-hour average windspeeds and directions during winter period (Period I), at Berthoud Pass, January 1952 - April 1964.

tinuously recorded from a generating anemometer, Weather Bureau specification F 420-C, during the winter of 1963-64.

Wind Direction

The prevailing wind direction, based on 8 compass points and 6-hour averages, is from the northwest (fig. 13). Data for 2 winters based on 16 points indicate a prevailing direction of west-northwest. Winds from the northwest, west, and southwest account for 76 percent of all wind directions; 20 percent are from the north and south; and only 4 percent are from the northeast, east, and southeast. During the early winter months, northwesterly winds prevail; in March and April (fig. 14), west and southwest winds prevail, and are associated with higher temperatures and increased precipitation.

Windspeeds at Berthoud Pass

The average winter windspeed is 16 miles per hour (m.p.h.). Changes in hourly windspeeds are gradual and follow a trend of either rise or fall over a period of 4 hours or more (see fig. 12). The highest 5-minute speed for

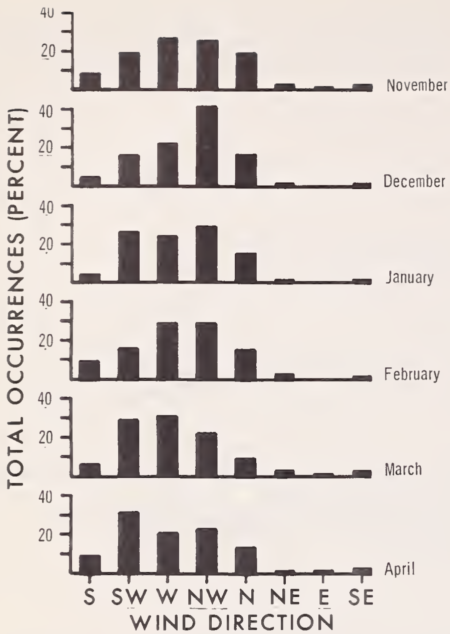


Figure 14.--Wind direction, in percent of occurrences, November - April 1951-64.

a given hour is seldom more than 10 m.p.h. greater than the hourly average. Sharp increases in speed do occur, however, and coincide with the advent of gusty periods. Recorded windspeeds have increased from 20 m.p.h. to 55 m.p.h. in less than 3 seconds.

At the chair-lift site, 6-hour average windspeeds exceed 30 m.p.h. only 3 percent of the time; they occasionally exceed 40 m.p.h. Marr (1961) noted spectacular increases in windspeed with increasing exposure; this has been experienced also at Berthoud Pass. Records from wind tower B, established October 1964 on Colorado Mines Peak east of Berthoud Pass (see fig. 2), show 6-hour averages that frequently exceed those at the chair-lift site by a factor of two or more through all speed ranges. During December 1964, 1-hour averages up to 83 m.p.h. and peak gusts to 108 m.p.h., corrected, (U. S. Weather Bureau et al. 1963) were recorded at wind tower B. Some rime ice has been encountered at this site (see fig. 8).

The maximum speeds for the period of record at the chair-lift site are not known since the recorder was out of order during some of the windiest periods. In one such instance, a 200-pound transformer was blown from a platform near the anemometer.[7] A 1-minute speed of 95 m.p.h. was recorded on December 24, 1955. The highest recorded windspeeds at the chair-lift site, January 1952-April 1964 are:

	Highest speed recorded (m.p.h.)	Date	Direction
Time interval:			
1 minute	95	Dec. 24, 1955	SW
1 hour	55	Jan. 31, 1963	SW
6 hours	49	Jan. 31, 1963	SW
12 hours	45	Dec. 24, 1955	SW

[7] *Personal communication with Richard M. Stillman, U. S. Forest Service, Denver, Colorado, 1961.*

Table 2.--Ratio of peak gusts to the 5-minute average windspeeds, November 12, 1963 - January 20, 1964

Item		November	December	January	Period
Number of 5-minute samples	N	194	1,204	1,047	2,445
Mean ratio of peak gusts to the average 5-minute windspeeds	R	1.40	1.51	1.57	1.53
Maximum ratio of peak gust to the 5-minute windspeed	R max.	1.82	2.40	2.61	2.61
Average windspeed in m.p.h.	μ	11.5	14.7	15.9	14.0

24 hours	40	Dec. 24, 1955	SW
1 month	19	Jan. 1953	--

Gustiness.--Data on maximum windspeeds of the type used for structural-design criteria are rare for the mountainous areas of the western United States. Gust factors at the Berthoud Pass chair-lift site were computed for November 12, 1963 to January 20, 1964, from data recorded with the generating anemometer. A 100-percent sample was taken, in which the criteria were 5-minute averages greater than or equal to 20 m.p.h. that contained at least one gust with a range of 10 m.p.h. or greater. There were 2,445 5-minute periods, or 13 percent of the total, that qualified. The mean ratio of the peak gusts to the 5-minute average windspeeds was 1.527 (table 2). Winner (1963) found a similar value using data from the Rhein-Main airport in Germany.

During the sample period at Berthoud Pass, the maximum gust was 88 m.p.h. Maximum gust ratio by speed classes was:

Average 5-minute speed in m.p.h.	Maximum gust ratio
20-29	2.61
30-39	2.46
40-49	2.00
50-59	1.68

Less than 1 percent of the samples fell in the two higher speed brackets, with only 4 percent exceeding 1.9. The mean ratio of the peak gusts to the 1-hour average speeds was 2.0 for the sample period. Windspeeds during November and December 1963 were slightly below average.

Windspeeds at Other Mountain Locations

Windspeeds vary greatly in the mountainous areas throughout the world (table 3), but the average monthly windspeeds at or near 12,000 feet m.s.l. in the north central Colorado Rockies are similar to those recorded at several alpine areas of western United States and Europe. The large mass of rough, mountainous terrain that extends several hundred miles west of Colorado's Front Range plays an important role in decreasing extremely high windspeeds that might otherwise be expected. As mentioned earlier, average windspeed at Berthoud Pass is 16 m.p.h.; on more exposed sections of the Front Range, the win-

Table 3.--Mean monthly windspeeds at various mountain weather stations, in order of decreasing windspeeds, November 1, 1962 - April 30, 1963

Station	State or country	Elevation of anemometer	Monthly windspeeds					
			Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
		Feet m.s.l.	Miles per hour					
Mount Fuji[1]	Japan	12,388	42	42	47	37	43	34
Mount Washington[1]	New Hampshire	6,262	25	36	39	49	41	36
Jungfraujoch[1]	Switzerland	11,729	27	29	25	24	26	25
Niwot Ridge[1]	Colorado	12,300	21	25	26	24	22	21
Pole Mountain[1]	Wyoming	8,200	22	22	21	21	18	--
Old Glory[1]	British Columbia	7,700	18	19	--	18	18	--
Pic du Midi[1]	France	9,381	15	19	20	17	20	17
Sonnblick[1]	Austria	10,191	22	16	18	15	18	15
Berthoud Pass[1]	Colorado	11,880	15	15	17	17	16	17
Arapaho Basin[1]	Colorado	12,400	--	--	--	15	14	15
Zugspitze[1]	Germany	9,718	13	20	15	14	17	11
Mauna Loa[1]	Hawaii	11,150	15	12	19	15	13	10
Sandberg	California	4,517	12	13	15	13	16	14
Kodaikanal	India	7,684	12	14	14	15	13	12
Sexton Summit	Oregon	3,836	14	13	11	15	13	11
Stampede Pass[2]	Washington	3,958	12	11	13	13	11	11
Weissfluhjoch[1]	Switzerland	8,835	13	13	12	8	11	9
Dubois 15 NE[1]	Wyoming	9,600	11	11	12	11	11	10
Bald Mountain[1]	Idaho	9,000	--	--	12	9	13	--
Peak Eight[1]	Colorado	11,600	--	12	11	12	9	--
Loveland Basin[1]	Colorado	11,800	8	10	12	10	10	--

[1] Anemometer is above timberline or is located on a treeless area.
[2] Data from U. S. Weather Bureau, Asheville, North Carolina; m.p.h. entries based on monthly mean of 1-minute windspeeds taken once each hour from 0400 to 1900 PST daily.

Table 4.--Mean monthly windspeeds for 3 years of record at several Front Range stations in Colorado

Station	Year	Elevation at anemometer	Monthly windspeeds			
			Jan.	Feb.	Mar.	Apr.
		Feet m.s.l.	- - Miles per hour - -			
Berthoud Pass	1965	11,880	17.3	15.7	14.0	15.8
Colorado Mines Peak	1965	12,493	29.0	28.9	23.7	23.0
Berthoud Pass	1964	11,880	16.3	15.1	15.5	16.9
Straight Creek Pass[1]	1964	12,500	25.2	23.3	23.2	22.7
Berthoud Pass	1953	11,900	19.0	17.0	16.0	--
Loveland Pass[2]	1953	12,000	20.0	18.0	16.0	--
Niwot Ridge[3]	1953	12,300	30.0	25.0	22.0	20.0

[1] 11.5 miles southwest of Berthoud Pass; averages prorated on basis of bimonthly readings; data by U. S. Forest Service.
[2] 11 miles southwest of Berthoud Pass; data from Colorado State Highway Department.
[3] 20 miles north-northeast of Berthoud Pass; data from Marr (1961).

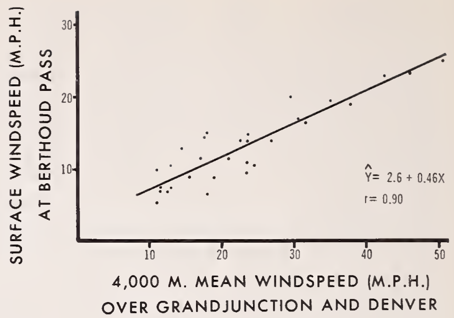


Figure 15.--Correlation of Berthoud Pass 12-hour average surface windspeeds with 4,000 m. windspeeds averaged for Denver and Grand Junction; SW, SSW, or S winds aloft; November - April 1962-63.

ter-month average is considerably higher--20 to 30 m.p.h. (table 4).

At Mount Washington, New Hampshire, (Blumenstock 1959) and the Jungfraujoch in Switzerland,[8] maximum hourly windspeeds exceeding 100 m.p.h. have been recorded; they have exceeded 90 m.p.h. at White Mountain, California (Pace 1963).

In the Colorado Rockies, the greatest recorded 1-hour average windspeed was on March 26, 1884 (U. S. Signal Office 1885), at 14,110 feet m.s.l. on the summit of Pikes Peak--112 m.p.h., corrected to 84 m.p.h. by means of the Robinson 4-cup hemispherical anemometer calibration curve (Brevoort and Joyner 1935).

Correlation with Winds Aloft

Because windspeed is a major factor in avalanche formation, surface windspeeds at Berthoud Pass were correlated with the 3,000 and 4,000 meter (m.) winds at Grand Junction and Denver from November 1962 through April 1963. A poor correlation (correlation coefficient r = 0.30) and a high degree of scatter were found when values for short intervals (5 minutes, or 1- and 6-hour surface averages) were used. A good correlation (r = 0.90), however, significant at the 1-percent level, was found with 12-hour averages when winds aloft were from the southwest at both Denver and Grand Junction (fig. 15). Upper winds from the west and northwest showed a great deal of scatter. A correlation coefficient (r = 0.76) for surface and upper winds, regardless of direction, over a 6-day time interval (fig. 16) was significant at the 1-percent level. The data for 4,000 m. winds aloft showed a slightly higher correlation with surface winds than did the 3,000 m. winds.

Significantly, upper wind directions corresponded very closely to the surface directions when winds aloft were from the southwest (fig. 17). Particularly interesting is the

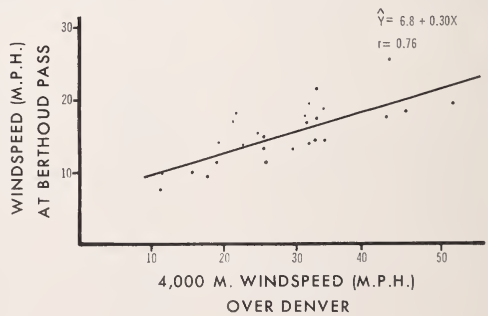


Figure 16.--Correlation of Berthoud Pass 6-day average surface windspeeds with 4,000 m. windspeeds over Denver, 16 directions, November - April 1962-63.

[8] *Personal communication with Dr. J. Haeflin, Chef des Wetterdienstes, Schweizerische Meteorologische Zentralanstalt, Zurich, Switzerland, October 14, 1964.*

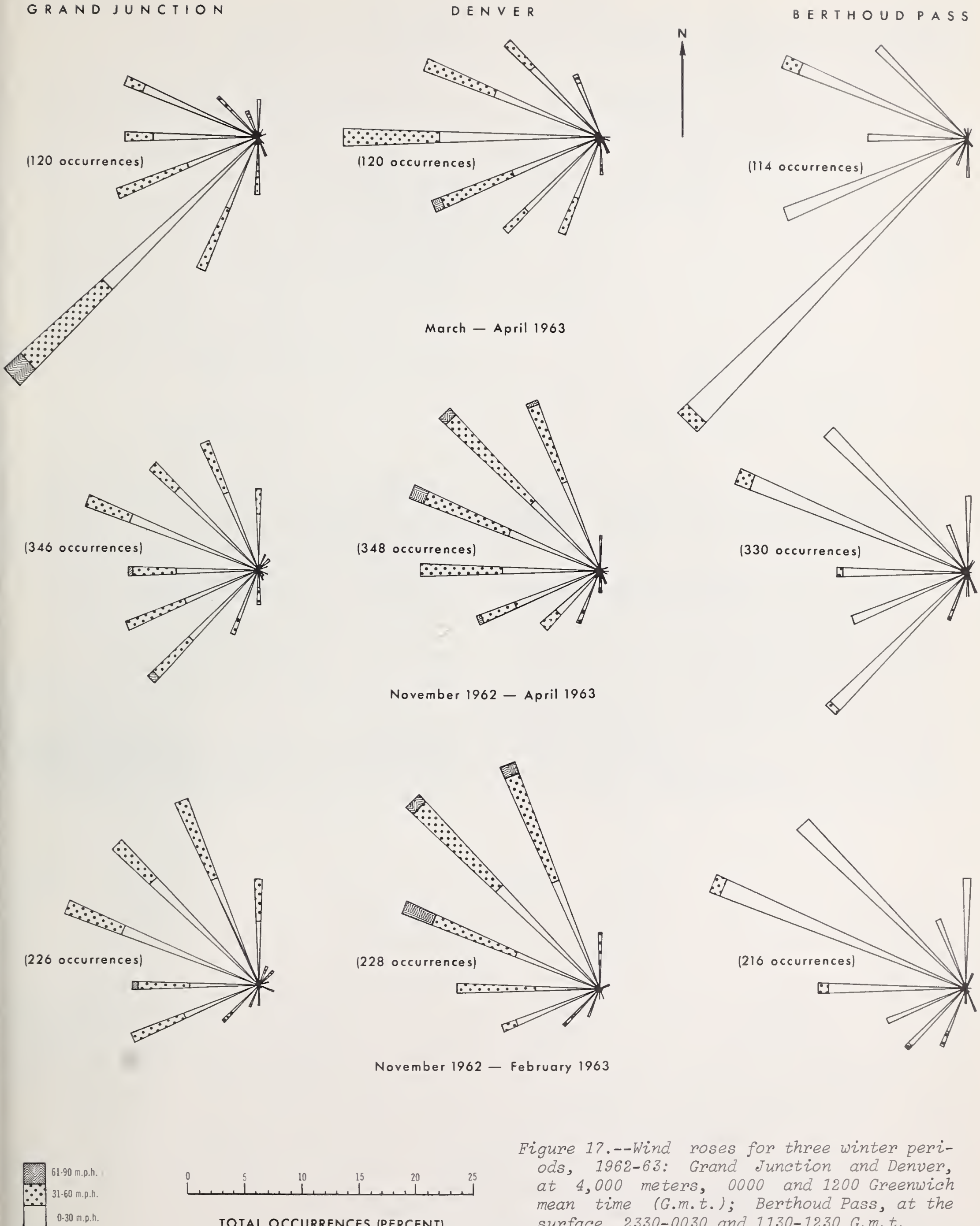


Figure 17.--Wind roses for three winter periods, 1962-63: Grand Junction and Denver, at 4,000 meters, 0000 and 1200 Greenwich mean time (G.m.t.); Berthoud Pass, at the surface, 2330-0030 and 1130-1230 G.m.t.

Table 5. --Comparison of upper wind directions (4,000 m.) at Grand Junction with surface winds[1] at Berthoud Pass, November 1 - April 30, 1963-64

Upper wind direction (4,000 m.) at Grand Junction	Total obser-vations	Corresponding surface wind at Berthoud Pass	
		Within +22.5°	Greater than +22.5°
	Number	Number of occurrences	
N	15	2	13
N-NW	31	11	20
NW	31	22	9
W-NW	26	20	6
W	15	12	3
W-SW	23	18	5
SW	17	17	0
S-SW	7	7	0
S	4	1	3
All other directions	4	1	3

[1] No entries made when less than 15 m.p.h.

prevailing southwest wind during the March-April period at 4,000 m. for Grand Junction and at the surface at Berthoud Pass.

Winds from the west and northwest showed the next best correlation, while north winds showed little, if any, relation to surface wind directions. When wind directions at Berthoud Pass and Grand Junction were compared (table 5), southwest winds aloft at 4,000 m. over Grand Junction appeared as southwest winds at Berthoud Pass 76.5 percent of the time, and were within 22.5 degrees of that direction all of the time. At the other extreme, north winds over Grand Junction never indicated north winds at Berthoud Pass.

The proximity of higher ground to the west of the Berthoud Pass anemometer site appears to induce a variable local effect (depending on stability conditions) that introduces both speed and direction bias. To forecast winds over the more exposed sections of the Continental Divide from winds-aloft data, an anemometer on a more isolated peak might be more reliable. To test this hypothesis, wind sensors were installed in the fall of 1964 on the 12,493-foot summit of Colorado Mines Peak. Figure 18 shows a frequency distribution of Berthoud Pass winds and winds aloft at Denver and Grand Junction.

Major Storms

At Berthoud Pass, the onset of a major winter storm has always been extremely difficult to anticipate. The sparse network of reporting stations in the Rockies, together with complex terrain features, precludes the recognition of any well-defined fronts and associated storm centers. This section is intended to give only a general insight into the large-scale atmospheric circulations associated with intense winter storms at the Pass.

Storms were divided into four types and simplified maps prepared (figs. 19-22), based on the 300 millibar (mb.) jetstream orientation and the 500 mb. flow patterns:

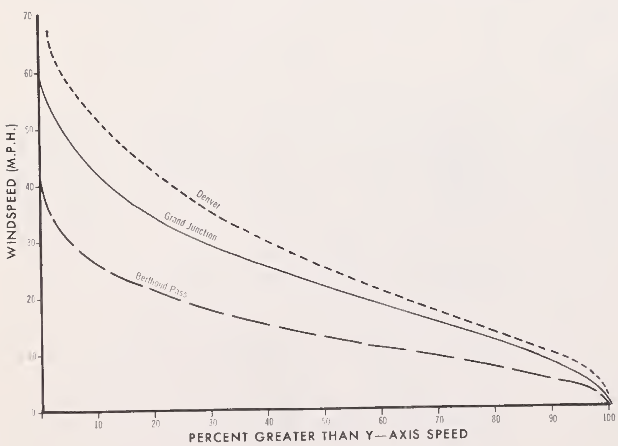


Figure 18.--Distribution of 5-minute average surface windspeeds at Berthoud Pass and 4,000 m. windspeeds over Denver and Grand Junction, November 5, 1962 - February 28, 1963.

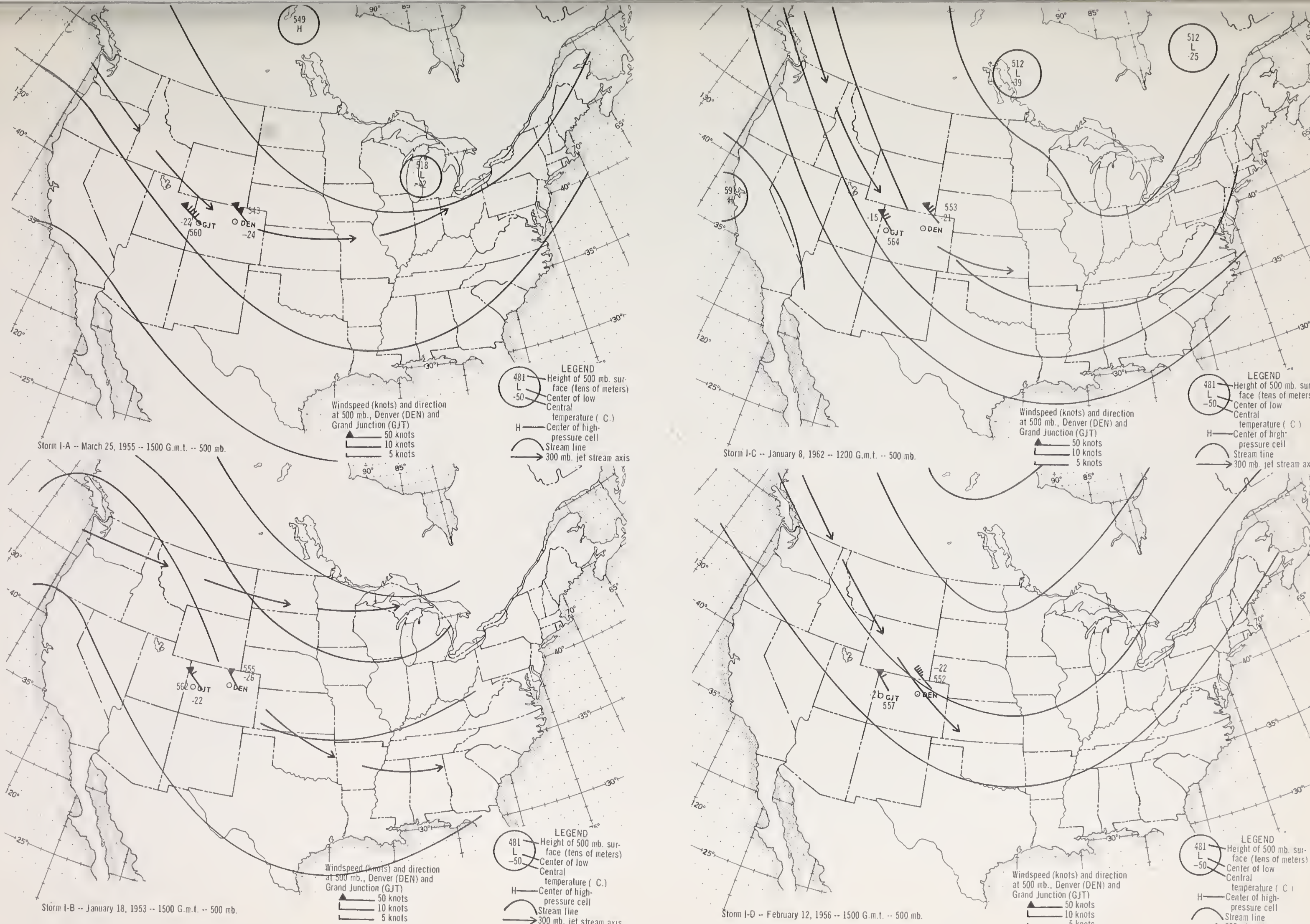


Figure 19.--Four storms of type I, 500 mb., Berthoud Pass, Colorado.

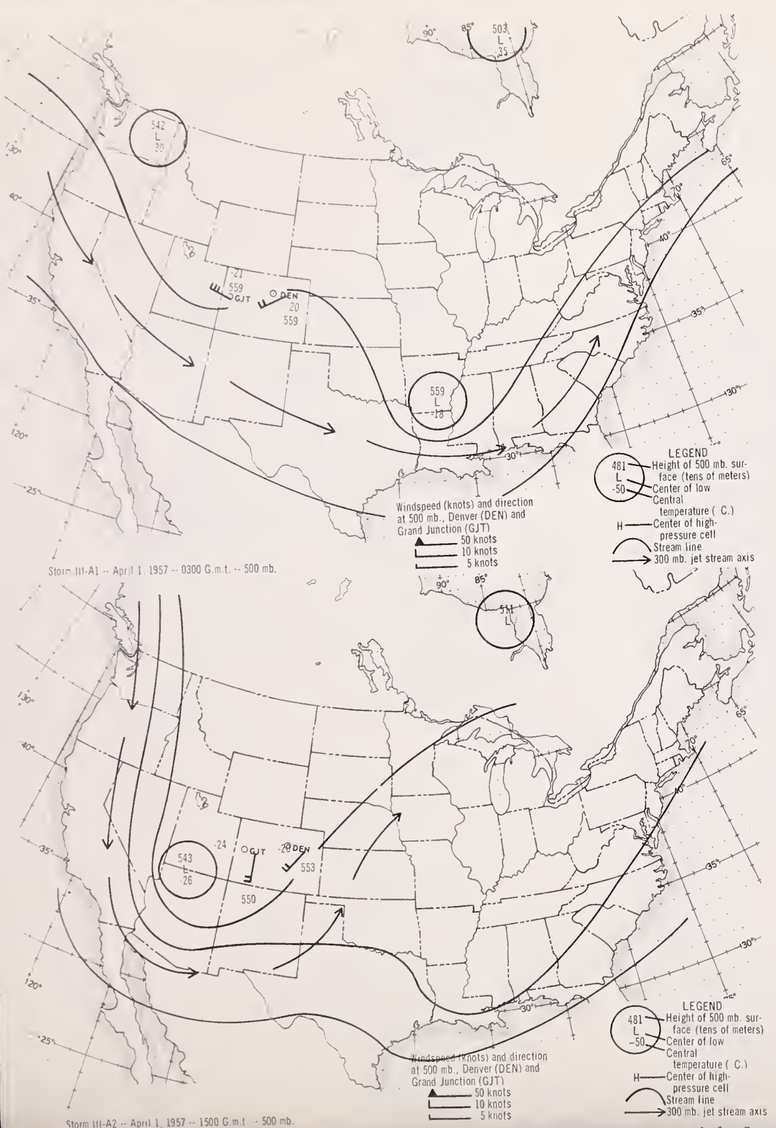


Figure 21.--Two storms of type III, 500 mb., with four

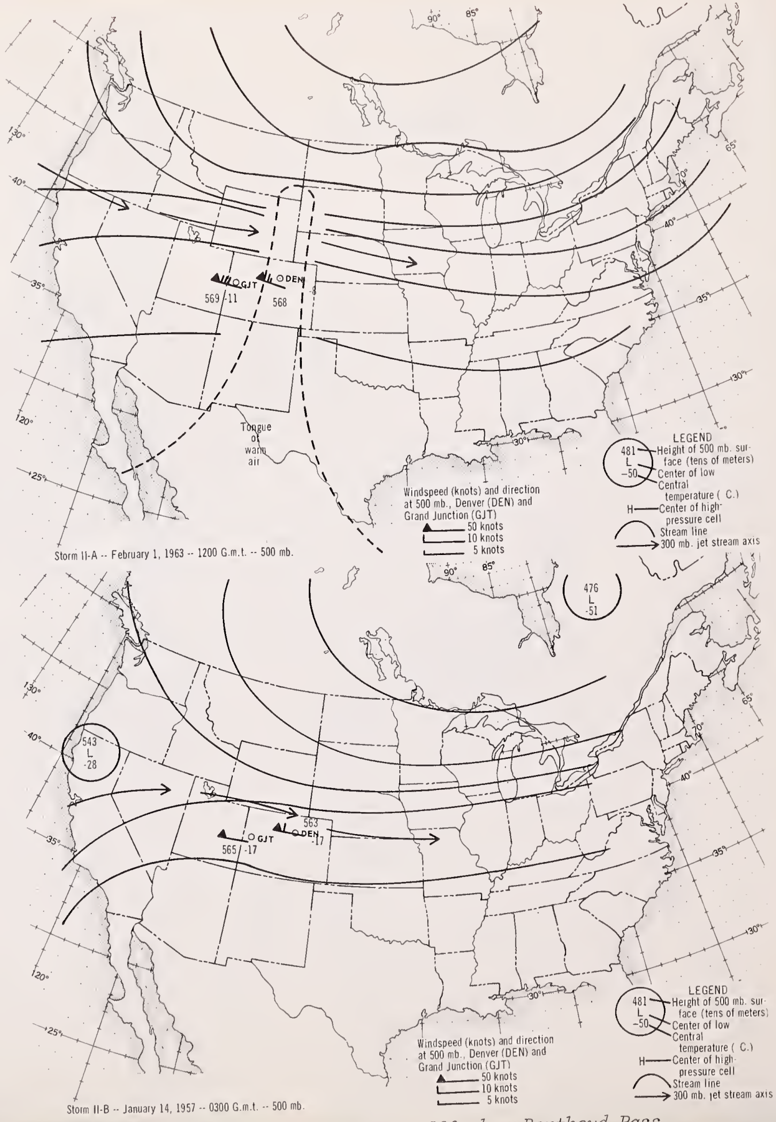


Figure 20.--Two storms of type II, 500 mb., Berthoud Pass, Colorado.

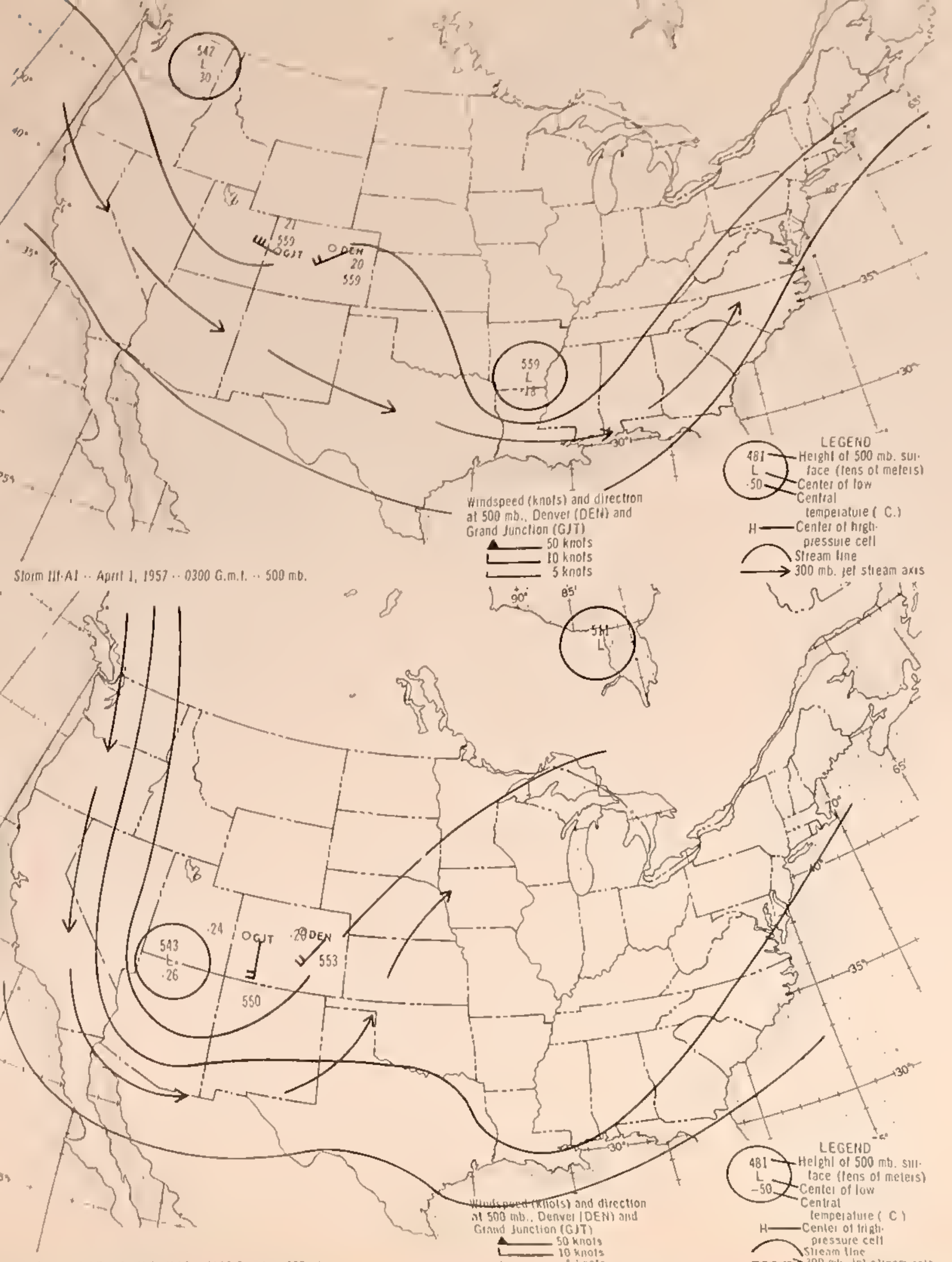


Figure 21.--Two storms of type III, 500 mb., with four time sequences for storm IIIA and two for storm IIIB.

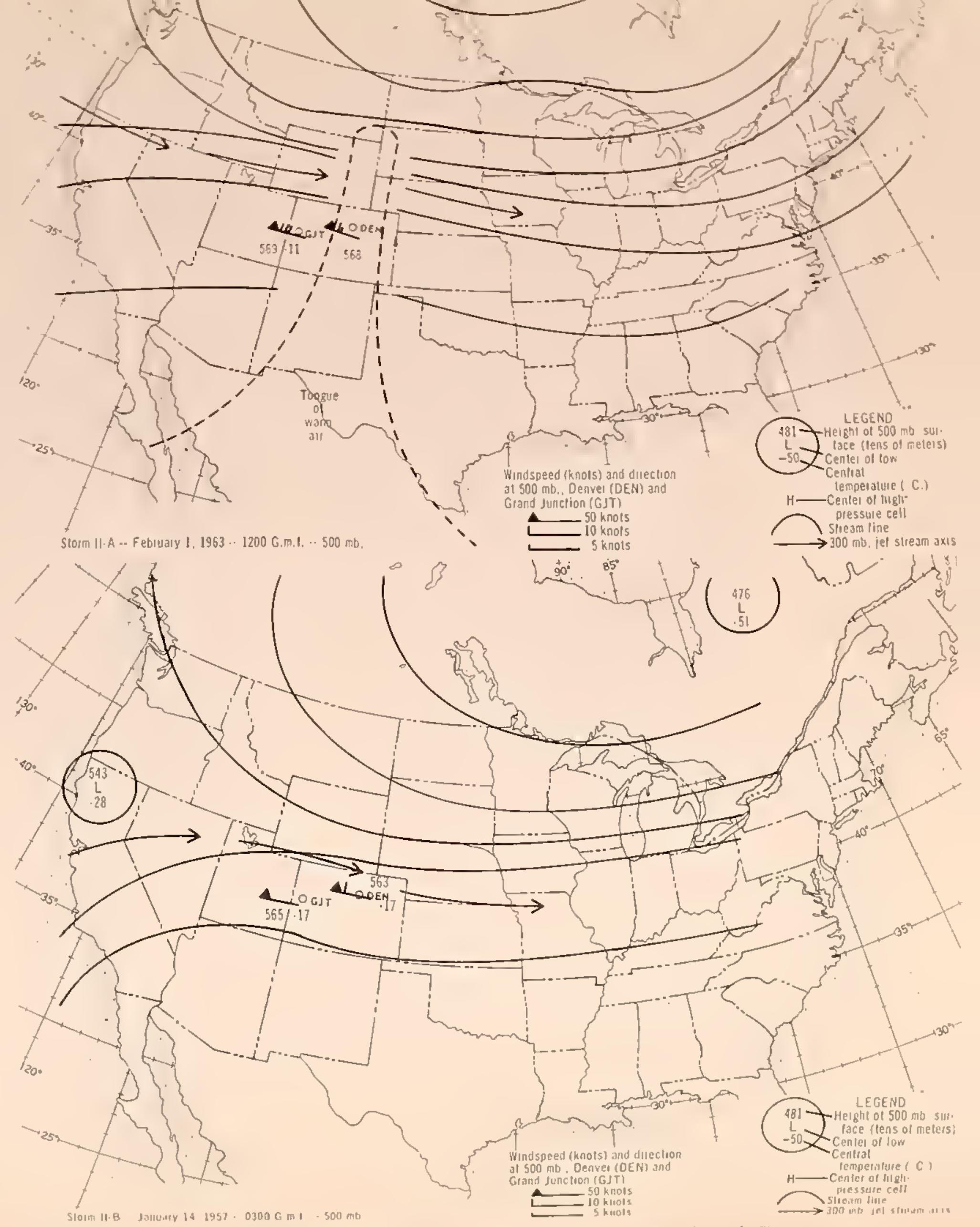
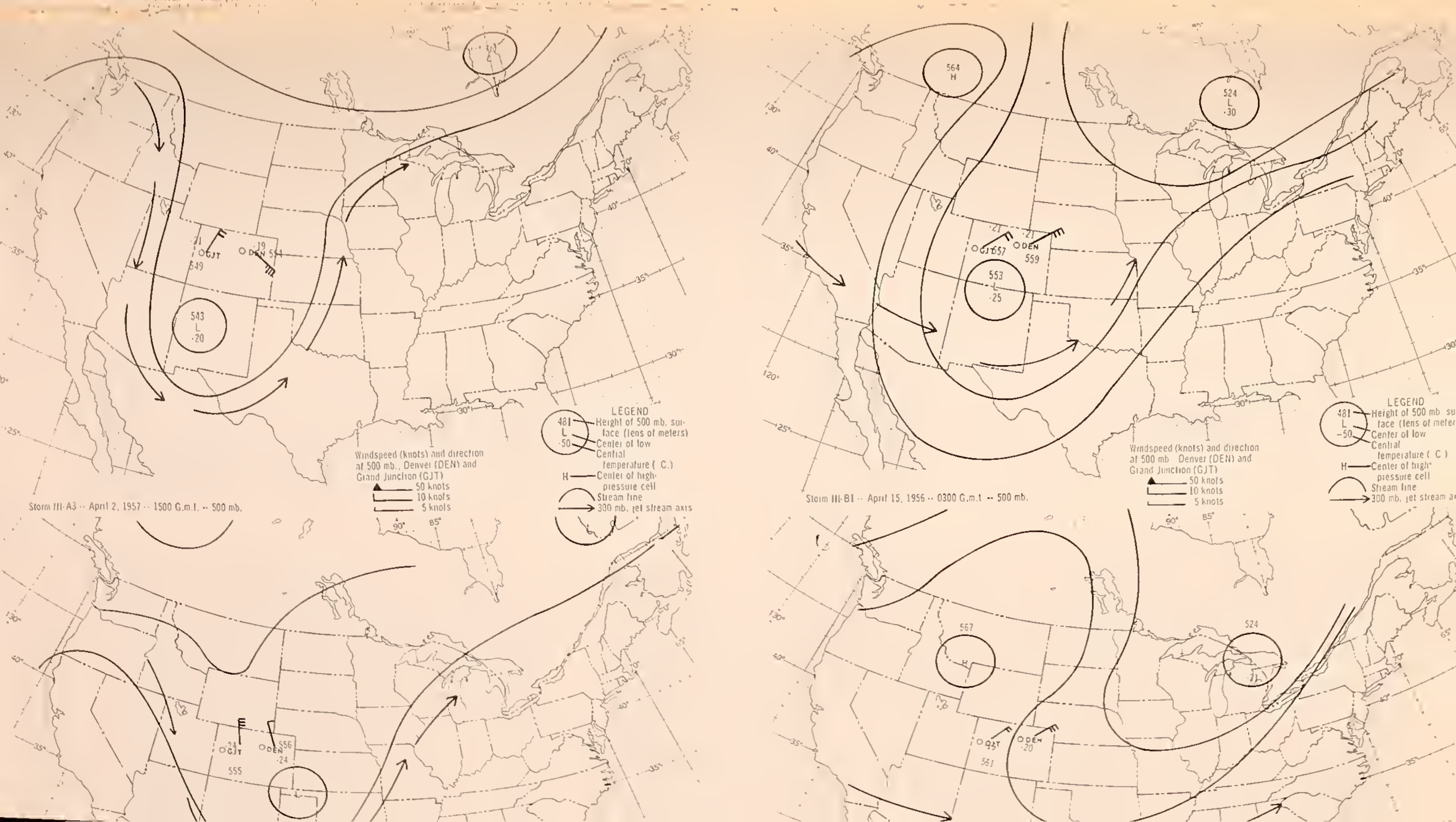


Figure 20.--Two storms of type II, 500 mb., Berthoud Pass, Colorado.



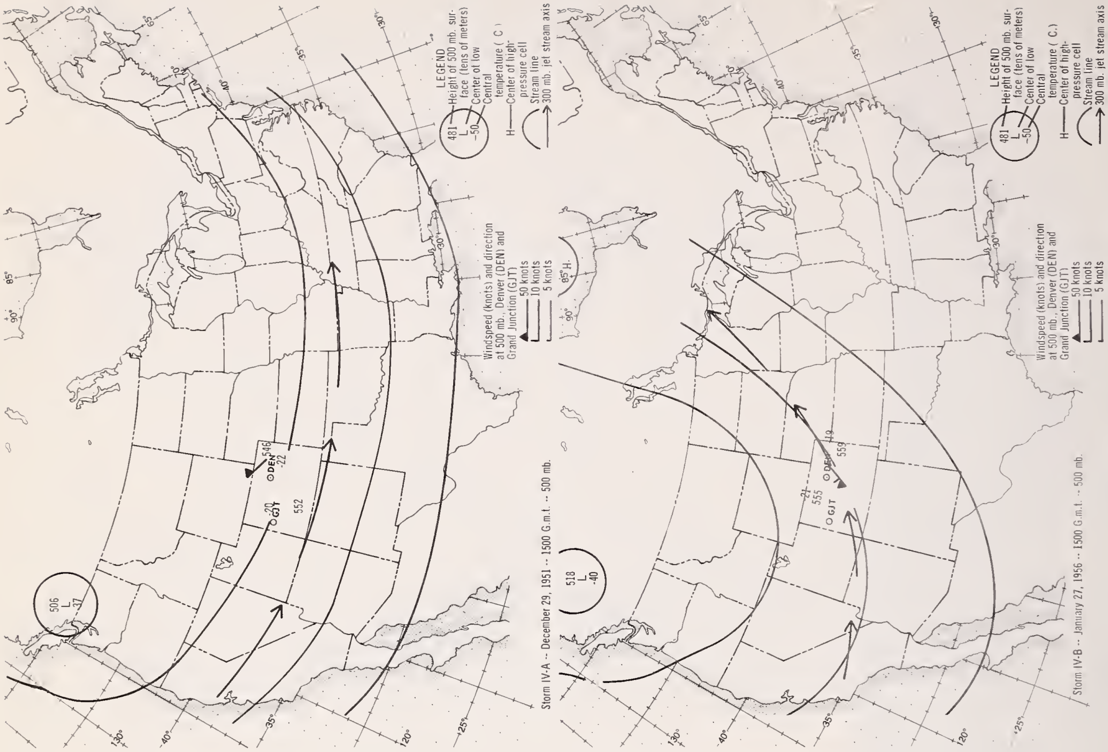


Figure 22.--Two storms of type IV, 500 mb., Berthoud Pass, Colorado.

	500 mb. surface	
	Direction of flow over Colorado	Trough location or type
Storm type:		
I (fig. 19)	Northwest	East of Divide
II (fig. 20)	West	West of Divide, with convergence
III (fig. 21)	--	Closed low
IV (fig. 22)	West or southwest	West of Divide, without convergence

Arctic air flanked the east side of the Continental Divide in storm types I, II, and III, and may have served as a lifting mechanism that caused heavy precipitation in areas near the Divide. Types II, III, and IV reached their maximum intensity at the Pass while the upper trough was still west of the Divide. They diminished rapidly when the upper trough moved east of the Divide and the 500 mb. dewpoints northwest of the station became too low to measure.

The presence of the 300 mb. jet axis near or over northern Colorado, a distinct feature which accompanied all the storms except the cutoff cold lows in type III, was a contributing factor in the strong surface winds which occurred during each storm period. Half the precipitation fell while 6-hour windspeeds averaged more than 23 m.p.h. The proximity of the jet stream during periods other than those discussed also produced locally severe weather conditions above 10,000 feet m.s.l.

The 10 largest storms of the last 15 winters were ranked according to the amount of precipitation received in a 24-hour period (table 6).

Surface temperatures at Berthoud Pass averaged 20° F. warmer than those at 500 mb. during the four storm periods. The barograph traces at this station show a tendency to reflect the 500 mb. surface height changes during the major storms as well as for other periods.

Table 6.--Major storms at Berthoud Pass, 1950-64

Rank	Storm started	Water equivalent		Storm duration	Maximum 6-hour average windspeed and direction		Upper air map type
		Maximum 24-hour period	Storm total				
		Inches		Hours	M.p.h.		
1	Apr. 1, 1957	2.38	3.02	40	29	N	III
2	Dec. 28, 1951	1.70	3.20	72	(40)[1]	(NW)[1]	IV
3	Jan. 27, 1956	1.60	1.60	24	21	SW	IV
4	Jan. 29, 1963	1.47	2.85	97	49	SW	II
5	Mar. 24, 1955	1.33	1.43	28	34	W	I
6	Jan. 17, 1953	1.10	1.10	24	24	SW	I
7	Jan. 6, 1962	1.09	1.97	66	40	N	I
8	Apr. 14, 1956	1.05	1.05	16	22	SE	III
9	Feb. 11, 1956	1.00	1.31	38	25	NW	I
10	Jan. 12, 1957	.85	1.60	52	20	SW	II

[1] Estimated.

Type I Storms

During each of the four type I storms (fig. 19), a strong northwest jet over Denver appeared at the 300 mb. level. All 500 mb. maps showed a strong northwesterly flow over the Colorado Rockies, a trough in the lee of the Continental Divide, and a high off the California coast. In storms I-A, I-B, and I-C, a stationary arctic front flanked the east side of the Divide at the surface, but during storm I-D, there were no surface fronts within 800 miles of Berthoud Pass station.

Type II Storms

The two type II storms were accompanied by strong convergence at the 500 mb. level (fig. 20). At 300 mb., the jet axis was oriented west to east over Denver. Accompanying upper air features were a low center off the southern Oregon coast, a high over Alaska, and the usual well-developed Hudson Bay low. In both storms, arctic air at the surface flanked the east slope of the Rockies. Because stationary, primary, and secondary cold fronts were involved, storm II-A showed a more complex surface pattern than storm II-B.

The Pacific occlusion that passed the station on February 1, 1963, during storm II-A greatly intensified the storm already in progress. A strong southwesterly flow over California pumped a large quantity of moist, unstable air into the western mountain region. The presence of this airmass aloft in conjunction with the fast-moving Pacific occlusion produced 0.80 inch of water equivalent in a 6-hour period.

For storm II-A, the 500 mb. map shows a tongue of warm, moist air extending northward from Mexico to Montana. The phenomenon produced unusually high temperatures at the Pass, and caused the heaviest concentration of rime ice ever recorded at the station. Heavy rime ice conditions were widespread from 12,000 feet up, and were accompanied by a fall of high-density snow. A very unusual winter event in the Front Range was the rain recorded up to 10,800 feet m.s.l. during this February storm.

Type III Storms

Type III storms (fig. 21) are associated with the classical, closed low aloft that crosses southern Colorado from the southwest or west. Both storms of this type showed strong surface highs of about 1,030 mb. in southern Canada, and both reached peak intensity before the upper trough crossed the Continental Divide.

Storm III-A, on April 1-3, 1957, was the most intense winter storm recorded at the Berthoud Pass since 1949 (see table 6).[9]

The approach trajectory of storm III-A was unusual: the 500 mb. storm center entered the State of Washington from the Gulf of Alaska on March 31, (III-A1), then intensified and moved rapidly southward on the east side of a strong northerly jet (III-A2). The low reached a position over southern Utah on April 1, then moved slowly eastward to northwestern New Mexico on April 2 (III-A3), and crossed the

[9] *The greatest recorded snowfall occurred in April 1933, when 94 inches of new snow fell in a 3-day period. Upper-air charts are not available, however, for this storm.*

Continental Divide on April 3 (III-A4). A striking feature during this storm was the persistence of the strong meridianal components of the jet stream (III-A2, III-A3).

At the surface, a well-developed wave appeared in northeastern Arizona on April 1, and moved northeastward to Grand Junction on April 2 where it intensified. The low then moved east of the Divide on April 3.

At Berthoud Pass, storm III-A began at 0600 hours on April 1, and reached its peak near 0800 on April 2, while the upper trough was still west of the Divide. After the upper low crossed the Divide early on April 3, the storm was reduced to flurries.

Storm III-B, on April 15, 1956 (fig. 21) moved in from southern California, crossed the Divide swiftly, and though intense, lasted only 16 hours. At 300 mb., the jet exhibited a much stronger zonal component than storm III-A, and was partially responsible for the fast eastward movement of the storm center. After crossing the Divide, this storm, unlike III-A, opened up into a trough.

The surface low accompanying storm III-B formed at Grand Junction on April 15, on a West-to-east quasi-stationary front. The low then moved rapidly eastward across the Divide on April 16.

Type IV Storms

Each of the two storms in type IV (fig. 22) was accompanied by a strong westerly or southwesterly jet with its central axis across Grand Junction and Denver at the 300 mb. level. At 500 mb., a trough extended from northern Idaho southwestward to an area west of the California coast. A closed low was present over British Columbia, and a strong ridge of high pressure dominated Alaska. This combination produced a strong northerly flow from Alaska south over the Pacific to a point near the 40th parallel, where the upper winds showed a westerly or southwesterly component.

During storm IV-A, at the surface, the "Grand Junction low" formed on a stationary Pacific front, moved rapidly eastward, and crossed the Divide into southeastern Colorado. The upper trough associated with this storm did not cross the Divide until the storm at Berthoud Pass had ended. During storm IV-B, however, a surface low with a Pacific system crossed north of the station.

PERIOD II: SPRING-FALL (MAY 1 - OCTOBER 31)

Continuous records of precipitation and temperature for this period were begun at Berthoud Pass in July 1961; wind, in May 1963 (see appendix, table 7).

May

Nearly all of the precipitation in May falls in the form of snow. Thunder and lightning occasionally accompany the snowfall, and upslope fogs are common in the postfrontal sector. The seasonal snowpack is isothermal, and alternately undergoes surface freezing at night and melting during the day. Maximum temperatures run between 35° F. and 50° F., while minimums usually range from 15° F. to 30° F. Severe winter-type storms are infrequent. Maximum average hourly windspeeds seldom exceed 35 m.p.h.

June

The thunderstorm season begins in June, with clear mornings and afternoon showers. Small amounts of snow fall occasionally, usually as flurries. The snowpack generally disappears during the third week. Temperatures are mild--between 30° F. and 60° F. Light winds prevail, except during thunderstorms. Peak hourly windspeeds seldom exceed 30 m.p.h.

July-August

Frequent afternoon thundershowers of rain, graupel, and small hail provide most of the precipitation. Intense lightning makes the operation of exposed instruments, above timberline, difficult and expensive. Precipitation intensities are low; 1-hour amounts rarely ex-

ceed 0.50 inch. The maximum 1-hour amount on record was 0.95 inch. Temperatures usually range from 35°F. to 65° F. but occasionally drop to freezing. Peak hourly windspeeds seldom exceed 20 m.p.h.

September-October

Thunderstorm activity declines, and clear, dry weather interspersed with some weak frontal activity is common. Most precipitation falls as snow, with moderate rime ice occurring above 12,000 feet m.s.l. Large, winterlike storms, although infrequent, have been recorded in both months. Upslope fogs following cold fronts commonly funnel through the Pass. Temperatures range from 15° F. to 65° F. Winds increase, with peak hourly speeds of 30 m.p.h. or greater.

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APPENDIX -- BASIC DATA

Table 7.--Summary of meteorological data at Berthoud Pass, Colorado, 1950-64

Meteorological data	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature[1] (Degrees F.):													
Mean	11	12	16	24	37	44	51	48	41	33	19	12	29
Maximum	40	42	49	56	61	68	72	72	65	61	51	41	72
Minimum	-28	-35	-20	-4	4	21	21	25	4	2	-25	-23	-35
Precipitation[2] (Inches):													
Mean	3.30	3.34	3.81	4.15	2.48	2.09	2.21	3.21	2.76	1.55	2.45	3.47	34.82
Maximum[3]	6.07	4.77	5.85	9.89	7.10	3.35	4.85	6.20	5.32	4.70	4.50	7.27	45.49
Minimum	1.13	2.08	1.09	1.61	.89	1.24	.47	.92	1.19	.49	.62	.88	25.46
Snowfall[4] (Inches):													
Mean	51	49	53	53	30	2	.5	[5] T	14	19	38	52	361.5
Maximum[6]	93	72	79	122	71	9	8	2	72	47	70	81	518
Minimum	19	26	16	19	2	0	0	0	0	3	11	16	267
Windspeed[7] (Miles per hour):													
Mean	16	15	16	15	13	11	10	10	10	11	14	16	13
Maximum:													
1 minute	--	--	--	--	--	--	--	--	--	--	--	95	95
1-hour average	55	--	--	--	--	--	--	--	--	--	--	53	55
6-hour average	49	38	40	40	--	--	--	--	--	--	38	47	49

[1] May-October: May 1962-64; June 1957, 1962-64; July-Aug. 1957, 1961-64; Sept. 1961-64; Oct. 1949, 1961-64.
[2] May-October: May 1950, 1957, 1962-64; June-Aug. 1957, 1961-64; Sept.-Oct. 1959, 1961-64.
[3] May and October values were estimated, using average density values for the maximum recorded snowfall for these months.
[4] May-October: Adjusted, using 1931-39 average with May 1950, 1957, 1962-64; June 1963-64; July 1961, 1963-64; Aug. 1962-64; Sept.-Oct. 1957, 1959, 1961-64.
[5] Trace.
[6] Exceeded earlier on: Jan. 1936--101 inches; Feb. 1934--128 inches; Mar. 1932--141 inches; Apr. 1933--154 inches.
[7] May-October: 1963-64 only.

Table 8.--Monthly and seasonal snowfall at Berthoud Pass, Colorado, 1926-39 (data taken by Clyde E. Learned)

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Total
						Inches							
1926-27	6	20	77	56	41	84	--	--	--	--	--	--	--
1928-29	--	21	42	31	--	--	--	--	--	--	--	--	--
1931-32	0	12	39	21	47	43	141	71	29	0	--	--	403
1932-33	2	41	47	52	63	33	65	154	50	0	--	--	507
1933-34	6	4	8	29	26	128	66	21	30	0	--	--	318
1934-35	8	3	54	58	26	28	57	128	71	6	--	--	439
1935-36	7	47	41	45	101	95	69	21	35	2	6	--	469
1936-37	23	25	21	46	43	76	59	50	10	9	--	--	362
1937-38	14	35	72	64	55	19	63	73	37	0	--	--	432
1938-39	0	4	45	60	48	69	80	55	15	0	--	--	376
1931-39:													
Mean	8	21	41	47	51	61	75	72	35	2	413 (Total)		
Extremes:													
Maximum	23	47	72	64	101	128	141	154	71	9	507 (1932-33)		
Minimum	0	3	8	21	26	19	57	21	10	0	318 (1933-34)		

Table 9.--Monthly and seasonal snowfall at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
						Inches						
1949-50	--	26	11	16	46	36	33	27	[1] (28)	--	--	--
1950-51	--	--	(70)	50	29	45	16	56	--	--	--	--
1951-52	--	--	(40)	81	40	43	43	58	--	--	--	--
1952-53	--	--	(28)	45	80	47	50	(50)	--	--	--	--
1953-54	--	--	(54)	47	19	33	61	(19)	--	--	--	--
1954-55	--	--	(41)	29	38	26	71	(35)	--	--	--	--
1955-56	--	--	(66)	63	90	62	36	(64)	--	--	--	--
1956-57	--	--	(33)	44	93	43	79	[2] (122)	(54)	--	--	--
1957-58	(3)	(7)	38	79	53	72	75	66	--	--	--	--
1958-59	--	--	(30)	71	51	72	56	36	--	--	--	--
1959-60	36	31	30	16	42	67	72	32	--	--	--	--
1960-61	--	--	22	46	25	36	57	64	--	--	8	--
1961-62	72	26	33	54	63	50	33	74	(24)	--	--	2
1962-63	3	(5)	26	40	57	64	47	23	2	9	0	0
1963-64	[3] T	8	16	41	34	38	61	68	19	9	0	2
Winter (November-April):												
Mean			36	48	50	49	53	53	289 (Total)			
Extremes:												
Maximum			70	81	93	72	79	122	414 (1956-57)			
Minimum			16	16	19	26	16	19	169 (1949-50)			

[1] Part or all of entries in parentheses were based on average density values of new snowfalls.
[2] 102 inches actually recorded April 1-13, 1957; last 20 inches based on average new snowfall density values. [3] Trace.

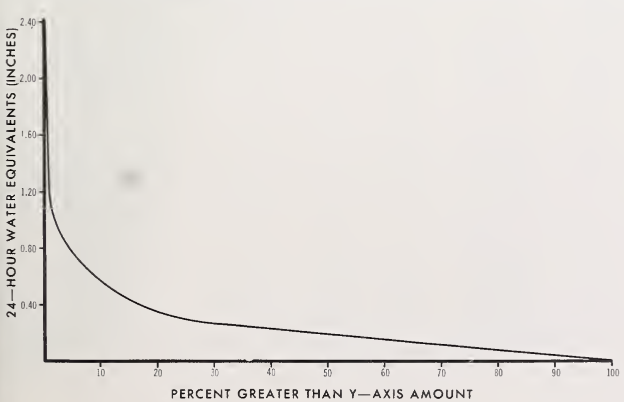


Figure 23.--Frequency distribution of the 24-hour water equivalents of the new snowfalls at Berthoud Pass, November - April 1949-64 (1,051 entries).

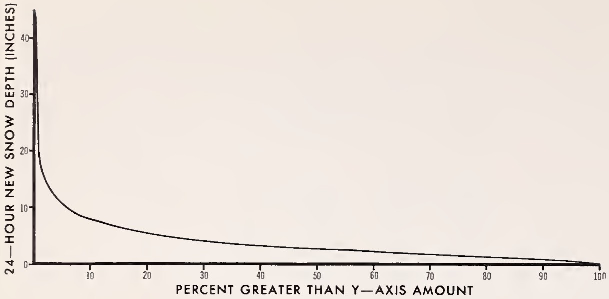


Figure 24.--Frequency distribution of the 24-hour new snow depths at Berthoud Pass, November - April 1931-39 and 1949-64 (1,420 entries).

Table 10.--Monthly precipitation at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
						Inches of water						
1949-50	--	2.45	0.62	1.19	2.76	2.08	2.96	2.21	2.64	--	--	--
1950-51	--	--	[1](4.35)W	(3.09)W	1.99	3.32	1.09	6.77	--	--	--	--
1951-52	--	--	(2.43)W	7.27	3.19	3.16	3.42	5.08	--	--	--	--
1952-53	--	--	(1.71)W	3.50	5.98	3.49	3.83	(3.50)	--	--	--	--
1953-54	--	--	(3.80)L	3.04	1.13	2.45	4.73	(1.61)	--	--	--	--
1954-55	--	--	(2.70)L	2.09	2.67	2.28	5.40	(2.28)	--	--	--	--
1955-56	--	--	(4.50)L	3.77	5.62	4.06	2.10	(5.13)L	--	--	--	--
1956-57	--	--	(2.35)W	2.99	6.07	3.07	5.61	9.89	5.10	1.24	0.47	3.98
1957-58	(1.72)W	(2.30)W	1.87	4.17	2.67	4.77	5.85	4.86	--	--	--	--
1958-59	--	--	(1.75)L	4.59	3.59	4.32	4.11	2.71	--	--	--	--
1959-60	[2](3.24)	2.97	2.06	.88	2.20	4.51	4.63	2.45	--	--	--	--
1960-61	--	--	1.50	2.75	1.42	2.15	3.76	5.33	--	1.70	4.85	3.76
1961-62	5.32	1.65	2.26	3.71	3.91	3.67	2.00	4.62	2.24	2.30	.96	.92
1962-63	1.24	.49	1.27	1.84	4.04	4.13	3.12	1.85	.89	3.35	2.09	6.20
1963-64	2.82	.97	1.31	2.66	2.25	2.67	4.47	4.03	1.69	1.87	2.70	1.19
Winter (November-April):												
Mean			2.30	3.17	3.30	3.34	3.81	4.15	20.07 (Total)			
Extremes:												
Maximum			4.50	7.27	6.07	4.77	5.85	9.89	29.98 (1956-57)			
Minimum			.62	.88	1.13	2.08	1.09	1.61	11.82 (1949-50)			

[1] Part or all of entries in parentheses were estimated by the ratio method from Winter Park data (W) and Loveland Basin data (L).
[2] Approximated by using average density value for a known amount of snowfall.

Snow depth

Table 11.--Maximum monthly snow depths at Berthoud Pass, Colorado, October-May 1931-64

Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
				Inches									Inches				
1931-32	--	12	24	48	68	97	94	55	1948-49	6	21	60	61	70	85	94	--
1932-33	--	25	43	54	78	106	[1]174	130	1949-50	14	14	22	43	57	74	82	--
1933-34	--	--	15	17	88	96	52	42	1950-51	--	--	--	66	80	92	115	--
1934-35	--	24	52	65	70	83	118	110	1951-52	--	24	72	74	87	94	101	--
1935-36	24	26	40	85	119	123	128	96	1952-53	--	--	28	48	58	67	72	--
1936-37	6	19	38	47	72	80	86	58	1953-54	--	--	38	37	44	60	56	--
1937-38	19	26	38	61	64	81	100	104	1954-55	--	--	30	43	53	73	76	--
1938-39	2	23	53	70	82	96	109	--	1955-56	--	28	48	64	74	70	83	--
1939-40	4	--	--	--	--	--	--	--	1956-57	--	24	34	58	61	72	108	95
1940-42	--	--	--	--	--	--	--	--	1957-58	--	24	46	55	71	86	95	--
1942-43	--	--	59	60	69	86	95	--	1958-59	--	19	42	52	73	81	83	--
1943-44	--	25	34	43	56	68	94	--	1959-60	--	36	40	54	73	93	87	--
1944-45	--	12	24	39	55	74	--	--	1960-61	--	16	34	41	49	60	76	70
1945-46	10	26	56	60	75	76	--	--	1961-62	26	33	44	64	77	79	90	72
1946-47	11	19	31	36	62	80	110	--	1962-63	2	10	20	36	55	60	52	35
1947-48	16	30	34	62	66	84	94	--	1963-64	6	10	31	32	47	67	72	64

[1] Occurred on April 22, 1933.

Table 12.--Snow depths[1] at Berthoud Pass, Colorado, taken from daily readings, November-April 1942-64

Season	November				December				January				February				March				April			
	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum
	Inches																							
1942-43	--	--	--	--	--	40	--	59	60	53	46	60	59	64	59	69	69	85	69	86	75	92	75	95
1943-44	--	11	5	25	23	24	22	34	38	30	30	43	43	54	43	56	56	55	55	68	68	76	64	94
1944-45	--	6	--	12	12	20	12	24	24	36	24	39	39	49	39	55	54	64	54	74	74	--	54	--
1945-46	10	17	10	26	25	36	26	56	55	54	53	60	55	70	55	75	74	67	65	76	64	66	--	--
1946-47	11	15	11	19	19	29	19	31	31	36	29	36	34	42	34	62	62	59	59	80	80	109	80	110
1947-48	16	11	16	30	30	30	30	34	38	42	38	62	59	57	55	66	66	72	66	84	80	74	68	94
1948-49	6	15	6	21	21	32	21	60	60	51	51	61	58	67	59	70	70	84	79	85	83	85	--	94
1949-50	12	14	4	14	10	14	8	22	16	25	16	43	44	48	43	57	56	58	52	74	77	72	64	82
1950-51	--	--	--	--	--	--	--	--	--	39	--	66	46	76	60	80	73	84	73	92	91	105	--	115
1951-52	--	--	--	24	22	35	22	72	69	55	55	74	70	72	69	87	75	79	75	94	95	90	75	101
1952-53	--	--	--	--	--	21	10	28	28	36	28	48	44	52	44	58	50	53	50	67	65	72	--	72
1953-54	--	--	--	--	--	31	21	38	31	32	29	37	34	35	32	44	44	47	43	60	56	41	--	56
1954-55	--	--	--	--	23	25	22	30	28	34	28	43	42	45	42	53	53	69	49	73	68	69	--	76
1955-56	--	26	--	28	24	30	24	48	37	47	33	64	59	72	56	74	65	70	63	70	63	79	--	83
1956-57	--	17	11	24	17	31	17	34	30	54	30	58	50	50	48	61	62	65	58	72	66	100	--	108
1957-58	6	18	6	24	23	29	22	46	41	39	36	55	54	63	51	71	62	75	61	86	82	85	80	95
1958-59	--	6	0	19	18	40	18	42	34	39	34	52	52	48	48	73	70	73	68	81	74	77	69	83
1959-60	--	27	--	36	34	33	32	40	38	50	38	54	48	66	48	73	74	93	74	93	87	67	58	87
1960-61	--	13	--	16	16	21	16	34	30	36	29	41	36	38	36	49	48	50	46	60	61	72	58	76
1961-62	21	29	21	33	40	35	33	44	56	63	46	64	67	67	59	77	--	77	67	79	88	88	61	90
1962-63	0	2	0	10	6	11	6	20	17	22	17	36	37	40	37	55	54	53	48	60	48	39	33	52
1963-64	6	5	4	10	8	17	8	31	25	28	23	32	30	37	30	47	44	52	43	67	60	69	59	72
Total	88	232	94	371	371	584	389	827	786	901	713	1128	1060	1212	1047	1412	1281	1484	1317	1681	1605	1627	898	1735
Mean	10	14	8	22	21	28	19	39	37	41	34	51	48	55	48	64	61	67	60	76	73	77	64	87

[1] Readings December 1942 to April 1951 taken at Bowl behind lodge; November 1951 to April 1964 at Q-12 Park.

Wind

Table 13.--Average monthly windspeeds at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
	Miles per hour											
1949-50	--	--	6	6	10	6	8	6	--	--	--	--
1950-51	--	--	--	--	--	6	--	--	--	--	--	--
1951-52	--	--	--	7	8	[1] 14	14	10	--	--	--	--
1952-53	--	--	--	--	19	17	16	([2])	--	--	--	--
1953-54	--	--	--	16	15	([2])	--	--	--	--	--	--
1954-55	--	--	--	13	16	16	18	([2])	--	--	--	--
1955-56	--	--	([2])	17	12	13	17	([2])	--	--	--	--
1956-57	--	--	([2])	([2])	16	14	17	([2])	--	--	--	--
1957-58	--	--	--	([2])	([2])	([2])	([2])	([2])	--	--	--	--
1958-59	--	--	--	--	([2])	--	--	--	--	--	--	--
1959-60	--	--	--	--	16	14	17	([2])	--	--	--	--
1960-61	--	--	--	([2])	([2])	15	15	([2])	--	--	--	--
1961-62	--	--	([2])	17	15	16	15	14	--	--	--	--
1962-63	--	--	15	15	17	17	16	17	13	10	10	9
1963-64	10	10	12	15	16	15	15	17	13	12	10	11

[1] Anemometer moved from 11,314 feet m.s.l. to 11,880 feet m.s.l.
[2] Data available, but for less than a full month.

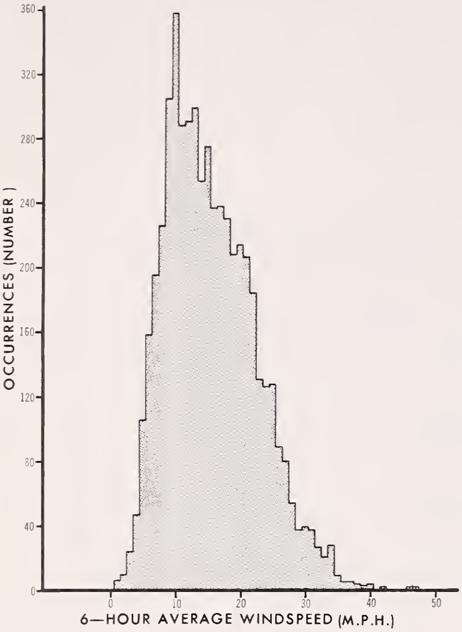
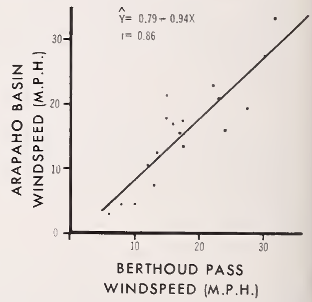


Figure 25.--Distribution of the six-hour average windspeeds (m.p.h.) at Berthoud Pass, Colorado; November - April 1951-63 (Mean = 16; Median = 15; Mode = 10).

Table 14.--The 20 greatest recorded 6-hour average windspeeds at Berthoud Pass, Colorado, with associated weather factors

Direction	6-hour average--				Date	6 hours ending at--
	Windspeed	Temperature	Precipitation	Pressure		
	M.p.h.	°F.	Inches	Inches of mercury		
SW	47	34	0	19.66	Dec. 24, 1955	1200
SW	46	28	.23	19.67	Jan. 31, 1963	2400
SW	42	33[2]	0	19.60	Dec. 24, 1955	0600
NW	42	14	.20	19.56	Dec. 7, 1957	1200
NE	40	2	0	19.52	Mar. 23, 1957	1800
S	40	25	0	19.38	Jan. 20, 1957	1800
NW	40	19	.17	19.52	Apr. 7, 1962	1800
NW	40	15	.01	19.71	Apr. 13, 1964	2400
N	40	12	.25	19.73	Jan. 8, 1962	0600
S	39	25	0	19.46	Mar. 12, 1964	1200
NW	39	2	0	19.20	Mar. 16, 1963	0600
SW	39	2	.18	19.43	Jan. 11, 1955	2400
NW	38	5	.22	19.67	Dec. 21, 1961	2400
S	38	32	0	19.60	Nov. 21, 1955	1200
SW	38	32	.40	19.58	Feb. 1, 1963	1200
SW	38	42	0	19.64	Mar. 28, 1963	1800
W	37	-7	.02	19.44	Jan. 26, 1963	1200
NW	37	21	0	19.58	Dec. 13, 1955	0600
SW	37	35	0	19.52	Dec. 23, 1955	2400
SW	37	14	0	19.50	Dec. 18, 1955	0600

Figure 26.--Correlation of 12-hour average windspeeds (m.p.h.) between Berthoud Pass and Arapaho Basin, January - April 1963.



Temperature

Table 15.--Average monthly temperatures at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
						Degrees F.						
1949-50	--	29	29	13	12	16	17	28	--	--	--	--
1950-51	--	--	--	--	[1] 12	16	15	[1] 22	--	--	--	--
1951-52	--	--	--	6	7	6	8	23	--	--	--	--
1952-53	--	--	--	[1] 8	13	7	20	[1] 15	--	--	--	--
1953-54	--	--	--	[1] 8	16	18	16	[1] 30	--	--	--	--
1954-55	--	--	--	12	8	6	17	[1] 22	--	--	--	--
1955-56	--	--	[1] 14	16	15	7	15	[1] 19	--	--	--	--
1956-57	--	--	14	13	11	20	17	[1] 20	--	[1] 42	50	49
1957-58	--	--	13	14	11	17	15	22	--	--	--	--
1958-59	--	--	[1] 19	17	12	13	15	25	--	--	--	--
1959-60	--	--	[1] 19	14	9	5	19	27	--	--	--	--
1960-61	--	--	[1] 18	12	12	12	17	21	--	--	45	45
1961-62	32	28	17	8	9	15	14	29	35	44	51	52
1962-63	45	34	25	16	8	16	18	26	39	46	54	49
1963-64	46	40	24	12	8	5	12	24	36	42	54	47

[1] Data include 15 days or more, but less than a full month.

Judson, Arthur.
1965. The weather and climate of a high mountain pass in the Colorado Rockies. U. S. Forest Serv. Res. Paper RM-16, 28 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Presents information basic to mountain meteorology and avalanche-control planning from Berthoud Pass -- an area representative of Colorado's avalanche zones near timberline. Describes and illustrates wind, temperature, snowfall, snow depth, rainfall, and related weather patterns from data collected irregularly 1926-49, continuously since then. Compares direction and windspeeds at surface at Berthoud Pass with 4,000 m. winds over Denver and Grand Junction. Analyzes weather relationships of 10 large winter storms at the Pass.

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